Primary Investigators (last names and affiliations)	Project Title	Year Funded
Ammann, Caspar, NCAR; D'Arrigo, Roseanne, Columbia University; Graham, Nicholas, Hydrologic Research Center	**The Paleoclimate Reconstruction (PR) Challenge: A Community Program to Benchmark Methods Used to Reconstruct the Climate of the Last 1-2000 Years**	**2008**

Abstract: Detailed understanding of the full range of past climate variability forms an important basis for the interpretation of the observed record and for gauging the response of the climate system to various forcings. The various methods and proxy networks used to reconstruct past climates exhibit many similarities, yet there are also important differences. It is unclear how much these differences result from either the selection of specific proxy networks, the potential inability of the included proxies to resolve information on all time scales, or the algorithms themselves. In this project, we assess the skill of different climate reconstruction methods by using synthetic climate proxy data derived from climate model output. Better understanding of the strengths and weaknesses of the reconstruction procedures is essential and will lead to a reduction of uncertainties and promote further convergence of our knowledge about the recent past.

We propose a last millennium Paleoclimate Reconstruction (PR) Challenge that offers: (1) an open and transparent platform for archiving, documentation, and dissemination of paleoclimate reconstruction methods; (2) a systematic evaluation and objective benchmarking of the skill of reconstruction procedures. This will be accomplished by applying realistic "pseudo-proxies" derived from long simulations with state-of-the-art coupled Atmosphere-Ocean-General Circulation Models (AOGCMs) in both open and blind-test reconstruction exercises as a well-controlled surrogate for the real world situation; (3) a strong motivation for the paleo community to explore reconstructions beyond mean annual or summer temperature and to attempt explicit seasonal as well as nontemperature reconstructions at hemispheric and regional scales; (4) to bring together the paleo, modeling and statistics communities to interact and to jointly assess the current level of knowledge and uncertainty in reconstructions and modeling of the last millennium climate.

The open access philosophy of this international cross-community effort will rekindle progress through collaborations across the disciplinary boundaries. Through these activities, the PR-Challenge will support and steer research to develop strategies for improving the reconstruction methods so that past climate variations can be better understood. A well-verified historical record forms the foundation from which assessment and predictions of future climate can happen. Providing the scientific communities with an opportunity for inspection and assessment of that climate baseline is the primary goal of this activity.

Black, David, Stony Brook University	High Resolution Tropical Atlantic SST Reconstructions of the Past 2000 Years	2009

Abstract: The tropical oceans are the primary source of interannual to decadal variability in the modern climate system, and one of the most basic variables of this system is sea surface temperature (SST). In the Atlantic, changes in SST patterns have a direct connection to changes in trade wind strength, ITCZ position, precipitation and drought patterns for the entire circum-tropical Atlantic basin, and rates of tropical storm and hurricane formation. Most of our understanding of subcentennial-scale tropical SST variability is based on instrumental records

that frequently extend back less than one hundred years. Additionally, modern instrumental data likely contains an anthropogenic component that is superimposed on the background natural variability.

Unlike the mid- and high-latitudes where tree ring data, ice cores, and lake sediments have provided high resolution surface temperature records spanning the last 1000-2000 years, the tropics lack equivalent long continuous high-resolution records of SST, a fact easily seen when one looks at the distribution of records used for hemispheric and global temperature reconstructions. Shorter high-resolution records exist primarily from coral data, yet these rarely extend more than a few hundred years into the past. Longer tropical records have been derived from lake sediments, but these represent the continental signal, not the marine.

This proposal seeks to create seasonal records of tropical Atlantic SST variability spanning the last 2000 years with a sample resolution of 1.0-2.5 years per sample. This will be accomplished through Mg/Ca analyses of seasonally-representative foraminifera from Cariaco Basin (Venezuela) sediments. The most recently-deposited of these sediments will be calibrated to historical instrumental SST data, and then the calibration will be extended down-core. A pilot study has successfully used this technique to generate an eight hundred year Spring SST record representative of the Caribbean and western tropical Atlantic

Broccoli, Anthony, Rutgers University	**Towards an Improved Understanding of Simulated and Observed Changes in Extreme Precipitation**	**2009**

Abstract: In its most recent assessment of the science of climate change, the Intergovernmental Panel on Climate Change (IPCC) concluded that it is likely that increases in the frequency of heavy precipitation events have occurred in the late 20th century. They further concluded that it is more likely than not that human-induced climate change is responsible for these increases, and that future changes are very likely as the climate continues to warm.

Extreme precipitation events occur when the atmospheric circulation causes water vapor to strongly converge over a region. Thus a simple hypothesis that has been offered to explain the observed and projected increases in the frequency of heavy precipitation events in a warming world is that circulation changes are small and the increased water content of a warmer atmosphere is the driving mechanism. If this were true, the magnitude of extreme precipitation events would increase at a rate constrained by the Clausius-Clapeyron equation, or ~7% K-1 of warming.

The goal of the proposed research is to better understand the physical mechanisms that underlie the near-ubiquitous increase in the frequency of extreme precipitation events that emerges from global warming simulations and also appears to be occurring in the real climate system. Some specific objectives are (1) to quantify the changes in the frequency and intensity of extreme daily precipitation events in a multi-model ensemble of climate model projections of future climate change and late 20th-century observations, (2) to determine how closely these changes conform to the 7% K-1 scaling that would be expected from the Clausius-Clapeyron equation, and (3) to understand the physical mechanisms responsible for any differences from Clausius-Clapeyron scaling. The project will focus on changes in extreme precipitation over North America. A novel aspect of the project will be the application of synoptic analysis of extreme precipitation composites in addition to the use of statistical analysis and climate diagnostic methods.

The proposed research is relevant to both the overall objectives of Climate Change Data and

Detection Program and to the specific foci that have been identified for FY09 proposals, which include an emphasis on extreme events and the utilization of existing simulations by multiple models. The improved understanding of expected changes in extreme precipitation that is expected to result from this project can help society anticipate and prepare for possible changes in the frequency and intensity of river flooding, which has a major impact on life and property and will likely be one of the more important impacts of climate change.

Bromirski, Peter, Scripps Institution of Oceanography	**Winter Wave Power Variability Along the U.S. Atlantic and Pacific Coasts**	**2010**

Abstract: Under **rising sea levels**, more wave energy will reach farther shoreward, accelerating **coastal erosion** and associated shoreline change. Extremes in wave power at the shore will have increasingly **severe societal impacts**. Changes in **winter wave power extremes** are directly related to changes in the character and track of extratropical cyclones. A tropical cyclone (TC) wave power index (WPI) for the western North Atlantic shows a significant increase along the U.S. Atlantic coast since the mid-1990's, both at open-ocean and at near-coastal locations. The TC WPI is well correlated with the observed increase in the Atlantic power dissipation index (PDI), and appears to be modulated by the Atlantic Meridional Mode (AMM). This association of the TC WPI to large-scale atmospheric variability suggests that winter WPI may also associated with broad-scale climate patterns. The WPI is a useful metric for assessing interannual and decadal wave power variability and trends, and may be an indicator of coastal erosion potential.

We propose to determine an Atlantic winter WPI using the network of **NOAA buoys** in the western North Atlantic, and characterize the extreme-event, monthly, and seasonal wave power variability to understand whether, and to what extent, the character of wave power extremes are changing. The buoy analysis will be extended both spatially and temporally with a parallel analysis of **WAVEWATCH III wave model** data. We will investigate the association of wave power extremes and winter WPI variability with the Pacific-North America (PNA) atmospheric pattern and other broad-scale North Atlantic **climate modes of variability**, e.g. NAO. We will also estimate the joint probability of extreme waves and extreme sea levels, both for hindcast waves and **NOAA tide gauge** observations and for predicted tides and sea level rise projections under high and low greenhouse gas emission scenarios.

The U.S. Pacific coast is also subject to strong winter waves, and has the benefit of much longer near-coastal buoy time series than the Atlantic coast. We will develop both **open ocean and near-coastal winter WPI** for the eastern North Pacific using available NOAA buoy data and parallel WAVEWATCH III data, analogous to that determined for the Atlantic coast. Associations with Pacific modes of climate variability (e.g. ENSO, PDO, PNA) and the Atlantic winter WPI will also be investigated. Patterns of wave power extremes, variability, and their coastal expression will be determined, as well as the joint probability of extreme waves and extreme sea levels.

Carton, James, U. Maryland; Lumpkin, Rick, NOAA/AOML	**Long-term Variability of Global Ocean Near-surface Currents**	**2010**

Abstract: The Global Drifter Program (former Surface Velocity Program, SVP) has been collecting near-surface ocean currents with surface drifters since 1979. Although drifter data coverage is spatially inhomogeneous, at least half of the World Ocean has velocity time series

longer than 15 years. The availability of this data opens new opportunities to explore observationally how the ocean circulation responds to changing atmospheric climate forcing. In addition, this data provides a unique opportunity to test the dynamical cores of ocean and coupled models. But exploiting this unique data set is complicated by a possible bias introduced by changes in instrumentation. This is a joint UMD/AOML proposal to provide calibrated, unbiased long-term records of surface currents needed for climate research by accounting for the differences in measurements due to changes in the types of surface drifters. By addressing the problem of bias in the surface drifter records we will produce long-term and continuous records of World Ocean surface currents (addressing bullet #1 of CCDD FY10 call) and by examining these calibrated records in order to understand whether and to what extent the character of the ocean climate is variable or changing we will address bullet #3.

The evidence for bias in the surface drifter records comes from examination of long time series. This examination shows surface currents to be strengthening rapidly in the same direction as the direction of time-mean current throughout the World Ocean, without a corresponding strengthening of the surface wind field. In the Southern Ocean, for example, this strengthening is at least • cm/s per year eastward, while in the trade wind regions, for example, this strengthening is up to • cm/s per year westward. This proposal will explore the possibility that these apparent changes are at least partly the result of bias in the instrument record.

One hypothesis we will explore is that the apparent strengthening of current is the result of a change in the drogue design after year 2000 and that change's impact on the water-following characteristic of the drifters. In order to verify this explanation we will need first to update the drifter metadata in order to include information about the design of each drifter drogue. This updating will require a fair amount of technical work because information about drogue design is available only from hard copy archives. Once the metadata is updated we will look at quasi-simultaneous and spatially collocated data collected by drifters with different designs in order to parameterize the effects of the design change as a function of environmental parameters such as winds and currents. We will begin by fitting the bias to observed current, wind, and wave parameters. The auxiliary data needed for this study are available online. Winds are provided by the atmospheric reanalyses (e.g. NCEP/DOE) or satellite scatterometers (QuikSCAT) while wave parameters are available from simulations (NOAA WaveWATCH model) or satellite altimetry. Our determination of bias will be incomplete without also accounting for Stokes drift and drifter slip, both of which are important in the high wind regions like the South Ocean. One outcome of the study will be a bias-corrected drifter data archive that will be made available via the NOAA/AOML servers, should such a bias be demonstrated in this study. A second outcome will be an evaluation of the nature and causes of low frequency changes in the near-surface circulation (on those time scales permitted by the data coverage). As part of the latter study we intend to perform comparisons of the surface currents with corresponding fields from ocean general circulation model simulations.

Cole, Julia, University of Arizona	**Reconciling Trends in Equatorial Pacific SST: Implications for ENSO Mechanisms**	**2008**

Abstract: Understanding the response of the El Niño/Southern Oscillation (ENSO) system to external climate forcing is a critical challenge for 21st-century climate prediction. Modeling and theoretical studies can be used in support of either a transition to a more El Niño-like base state or its opposite, a more La Niña-like base state. One approach to reconciling these discrepancies is to examine the instrumental record of sea surface temperature (SST) variability in the tropical

Pacific. However, observations are scarce to nonexistent in critical regions in before the mid-20th century, and SST products that span the past century depend on statistical infilling methods to create gridded fields. Trends across the 20th century derived from different SST products lead to opposing conclusions on how the base state of the Pacific has changed.

We propose to use an existing collection of coral cores to address this discrepancy, by generating replicated records of SST from three equatorial Pacific sites using Sr/Ca. This work is collaborative with Dr. Sandy Tudhope (University of Edinburgh) who will work with the PI on the analysis of samples and on interpretation and publication of results. These cores span 110-150 year intervals beginning in the mid-late 19th century and ending in the last decade of the 20th century. Five of the six have been fully analyzed for oxygen isotopes, which yields a mixed SST-salinity signal. Trends in these records are larger than one would expect (1-2.5°C), leading us to conclude that salinity and potentially other factors are obscuring true temperature changes. Sr/Ca appears to act as a temperature tracer uncontaminated by salinity artifacts, and preliminary measurements suggest much smaller trends. We will examine cores from northern New Guinea (Laing and Madang Islands), Kiribati/Gilbert Islands (Maiana and Onotoa Atolls) and Jarvis Island. Instrumental records from these sites mimic the discrepancies identified in more complete analyses of the instrumental SST fields and we have confidence that SST reconstructions from these sites are therefore suitable for resolving the critical differences among existing instrumental SST datasets. The development of replicated records from each region also contributes to reducing the uncertainties associated with single core interpretations.

By combining Sr/Ca and δ18O records from these corals, we will also determine to what degree we can isolate coherent patterns of low-frequency and secular variability in seawater δ18O (~salinity). We will test the idea that low-frequency coral δ18O variance coherent across large distances reflects processes that change surface seawater salinity, such as advection of water masses with varying salinities and the migration of atmospheric convergence (precipitation) zones. And we will be able to characterize the relative contributions of SST and seawater isotopic changes to interannual-decadal variations associated with ENSO indices. Replication of these records will enhance signal/noise and minimize nonclimatic sources of bias.

Cook, Edward, Columbia University	**Towards Near-Global Reconstruction and Understanding of Hydroclimate Variability and Change Over the Past Several Centuries**	**2010**

Abstract We propose to develop a gridded reconstruction of past drought over Europe, North Africa, and the Middle East from a network of exactly dated annual tree-ring records covering the past several centuries to millennium. The development of this 'Old World Drought Atlas' (OWDA) will complement the existing 'North American Drought Atlas' (NADA) and the 'Monsoon Asia Drought Atlas' (MADA) nearly completed now as part of a National Science Foundation project on "Tree-Ring Reconstructions of Asian Monsoon Climate Dynamics". By developing the OWDA, we will greatly expand the coverage of gridded drought reconstructions across the Northern Hemisphere to allow for more complete synoptic-scale comparisons of hydroclimatic variability at annual-to-centennial time scales. The OWDA will prove an invaluable tool for assessing the nature and causes of climate variability and change over the last several centuries to millennium. In combination with the NADA and the MADA, it will provide near hemispheric annual reconstructions of drought severity. Currently, it is hard to assess causes of the decade to
centennial changes seen in the NADA because much of North America is sensitive to both

Pacific and Atlantic SST variations. By examining hemispheric patterns, and bringing in regions where the Pacific and Atlantic influences are stronger or weaker, we stand a much better chance of being able to assess how terrestrial hydroclimate change over decades and centuries links in to ocean variations. Furthermore, the OWDA, in combination with the NADA and MADA will provide invaluable information for model simulations of the climate of the last millennium whether coupled or forced by proxy-reconstructed SSTs.

Curry, Judith, Georgia Institute of Technology	**Climatology of African Easterly Waves**	**2010**

Abstract: Approximately 60% of Atlantic tropical storms originate from AEWs and nearly 85% of all intense hurricanes (categories 4 and 5) have their origins as an easterly wave. A climatological data set of AEWs is needed to enhance understanding of the processes responsible for tropical cyclogenesis and to improve the prediction capability of genesis. When examined on a seasonal basis, AEWs can provide an important link between seasonal North Atlantic tropical cyclone characteristics and climate teleconnection patterns including modes of Atlantic and Pacific variability. However, there is presently no climatological data set for AEWs. We have designed an objective, physically based tracking algorithm for AEWs. Using this tracking algorithm, we have developed an AEW dataset from 1980 to 2001 using ERA-40 reanalysis and OLR. We propose to extend this dataset forward in time using both the ERA-Interim and NCEP-NCAR reanalyses, and backwards in time using the NCEP-NCAR reanalysis. We will use historical GOES data to extend the dataset back to 1966 and will test the uncertainty of the tracking scheme without including OLR data to see if useful tracking results can be obtained back to 1948, the start date of the reanalysis. For each AEW, the data set will include date of occurrence, average speed, propagation path, intensity when leaving the African continent and along the path, and approximate wavelength. The AEW dataset will be further integrated with HURDAT hurricane data to identify waves that developed into tropical cyclones. To test and demonstrate the utility of the AEW dataset, we will conduct studies relating AEWs to tropical cyclogenesis using the HURDAT dataset (under separate NSF funding), and we will examine the interannual and interdecadal variability of AEWs in the context of known climate teleconnection patterns including modes of Atlantic variability (Atlantic Nino-NAO-AMO-AMM) and Pacific variability (ENSO-NPGO-PDO). Given that a portion of AEWs enter the Eastern Pacific basin, we will also use the tracking algorithm to generate a separate data set of easterly waves in this basin. Comparisons of both data sets will serve to obtain a better estimate of the portion of waves that travel from the Atlantic to the Pacific as well as those that originate insitu. Detection of Pacific easterly waves is also important for the United States since during the summer months, these waves can extend northward as far as the desert southwest producing spells of intensified shower activity within the summer monsoon.

Easterling, David, NCDC; Kunkel, Kenneth, Desert Research Institute	**Climatology and Trends in Extratropical Cyclones Over the Past 100 Years**	**2009**

Abstract: Extratropical cyclones (ETC) are the major feature of mid-latitude weather during the colder times of the year and are responsible for many of the extreme weather types experienced at mid-latitudes. A major uncertainty in climate change is how extratropical cyclones have changed both globally and regionally over the past 100+ years. One of the 12 recommendations (4.4) for improving our understanding of climate extremes contained in the Climate Change

Science Program (CCSP 2008) Synthesis and Assessment Product 3.3: *Weather and Climate Extremes in a Changing Climate* is to use reanalysis products from new efforts currently underway to study global and regional changes in extratropical cyclones. Past efforts to examine changes in strong extratropical cyclones have relied on past reanalysis efforts that are restricted to the period since 1948 or later. Furthermore, older reanalysis data sets are not homogeneous due to issues such as the introduction of satellite data in the 1970s. A current reanalysis effort that can help resolve these issues utilizes only surface pressure for input and begins in the early 1890s (Compo, et al. 2006). This project, NOAA Historical Reanalysis, is being run by the NOAA Earth System Research Laboratory using the Climate Forecast System (CFS) developed at NOAA National Centers for Environmental Prediction (NCEP).

In this project, we propose to construct a global climatology of extra-tropical cyclones utilizing the Historical Reanalysis data set currently under construction set for completion in mid-2009 (G. Compo, personal communication). Once the climatology has been established, the Historical Reanalysis will be used to examine temporal and spatial variability and changes in storms, both number and intensity. An online database of cyclone tracks and associated products will be created.

Overarching goals in the analysis are to identify latitudinal shifts over time in the mean storm track, to determine whether there are longitudinal variations in such shifts, and to investigate mean changes and spatial variability in storm number and intensity. Within these overarching goals, we propose to investigate whether there were changes in storm tracks and intensities coincident with notable global and regional climate variations, including the rapid global warming in the early part of the 20th Century following by cooling during the middle of the 20th Century, the wetness in the western U.S. during the early part of the 20th Century, and the drought during the Dust Bowl era of the 1930s. We will also examine whether there were changes over time in the relationships between storm tracks and climate modes of variability, particularly ENSO.

Emile-Geay, Julian, U. Southern California; Evans, Michael, U. Maryland; Noone, David, U. Colorado; Thompson, Diane, U. Arizona	**Maximizing the potential of tropical climate proxies through integrated climate-proxy forward modeling**	**2010**

Abstract: The proxy record of tropical climate over the past millennium potentially provides important validation for numerical simulations of future climate change. However, considerable uncertainty arises from the multivariate and nonlinear nature of the response of many important proxy datasets to climate forcings. This limitation is particularly acute for oxygen isotope records in fossil corals and tropical tree-ring cellulose, which constitute key archives of the variability of the El Niño - Southern Oscillation and monsoon systems, both internal oscillations with large societal impact. To maximize the utilizable information present in such proxy records, our approach rests on the 'top-to-bottom" modeling of the essential aspects of the tropical water isotope cycle, from the physics of stable isotope fractionation and transport in the atmosphere/ocean system, to the chemistry of their incorporation in coral and tree-ring archives.

We will develop process models of physical and chemical processes that realistically represent the relationships between climate variables and the oxygen isotopic composition of reef corals and tree rings. These models will be driven with the output from efficient models of the global

coupled ocean-atmosphere system and the physical controls on the distribution of stable isotopes in precipitation and the surface ocean circulation. Following validation against 20th century observations, the coupled climate-isotopeproxy model will be driven by estimates of external climate forcing over the past millennium, and output compared to actual proxy observations. A fully ompartmentalized error and sensitivity analysis will determine the extent to which the model system is in agreement with the observations.

Forest, Chris, Penn State	**Identifying Structures and Impacts of Uncertainty on Climate Change Detection Results**	**2009**

Abstract: The proposed work in the original grant addresses the question of how to incorporate the uncertainty in observational errors, mainly from potential systematic biases, into the climate change detection statistical algorithms. The potential biases are mainly an issue with sea surface temperatures where a fraction of the original data have unknown sources. The bias corrections for these data must be inferred from the data for which it is known how the original temperatures were measured. Typically, the relative fractions of each measurement type from the known data sources are then applied to the data for the unknown measurement types. This has a potential bias that will be explored here and formalized in the statistical detection algorithms.

In the original proposal, the major questions to be addressed were: To what extent can we:

1. estimate further the biases and structures of observational uncertainty?
2. clearly identify robust patterns of variability from climate model results?
3. estimate the impact of these biases and uncertainty on CCD results?
4. distinguish between bias structures and variability structures?

At this time, in work with Bruno Sansó, we have developed the statistical tools to discuss item 2, and in the continuation of this grant, we will proceed with incorporating the bias and uncertainty components from the observational data to advance items 3 and 4.

The proposed work will proceed by exploring the error structures in the observational data sets (e.g., GHCN-ERSST, HadCRUT3, and HadAT2). The effort will continue to make use of the archive of atmosphere-ocean general circulation model (AOGCM) simulations available at the PCMDI IPCC Data Portal for work on the IPCC Fourth Assessment Report. These AOGCM data for the 20th century and pre-industrial control simulations will be used directly in the optimal detection algorithm. The majority of the effort will be to quantify the errors and, where possible, spatio-temporal structures. These multiple sources of estimated errors will be incorporated into the climate change detection algorithm. The current method is a hierarchical Bayesian framework for estimating the detection statistics that incorporates the identified error sources.

Fu, Qiang, University of Washington	**Detecting Atmospheric Trends and Investigating Their Causes**	**2008**

Abstract: The inconsistency between the satellite-inferred tropospheric temperature trends and the trends near the surface based on *in situ* observations has long been used to challenge the ability of current global climate models (GCMs) to predict climate changes, the reliability of the observational data used to derive temperature trends, and the reality of human-induced climate change. Recent new analyses of satellite and balloon-borne measurements of lower- and

midtropospheric temperature show warming rates similar to the surface temperature (CCSP 2006; IPCC 2007), largely reconciling a discrepancy noted in previous assessment (NRC 2000; IPCC 2001). However, while new analyses and data are consistent with the results from GCMs at the global scale, discrepancies in the tropics remain to be resolved (CCSP 2006). Furthermore, enhanced mid-latitude tropospheric warming and stratospheric cooling are identified from the satellite observations (Fu et al. 2006), which indicates expansion of tropical circulation. Johanson and Fu (2007) also found unexpected large stratospheric warming over half of the southern hemisphere high latitudes in the winter and spring seasons. Assessment of these changes and investigation of their causes have direct implications to improve our understanding of climate feedback processes (Coleman 2001), poleward shift of subtropical dry zone and the increased frequency of midlatitude droughts (Seidel et al. 2007), and recovery of ozone hole in the Antarctic (Solomon et al. 2005).

The overall objective of our proposed work is to assess atmospheric trend patterns and investigate their causes. We will focus on the vertical structure of tropospheric temperature trends in the tropics, the large stratospheric warming patterns in the southern hemisphere high latitudes, and the expansion of tropical circulation. We will assess these changes by analyzing multiple satellite datasets along with radiosonde observations and addressing the observational uncertainties in the context of defining the significance of these trend patterns. We will examine the causes of these changes by comparing observations with GCM simulations. A wide range of GCM simulations in support of the IPCC 2007 report, including pre-industrial control runs, 20th century experiments with various natural and anthropogenic forcings, and 21st century runs, will be used. In addition, the GCM simulations with prescribed SST and those including good representation of the stratosphere will also be analyzed. As part of our research effort, we will continue to provide a high quality tropospheric temperature product for the climate research. This proposed project will directly contribute to the overall goal of the NOAA Climate Program to improve our ability to observe, understand, predict, and respond to changes in the global environment.

Groisman, Pavel, National Climatic Data Center	**In-situ Precipitation Dataset in High Latitudes of the Northern Hemisphere for Calibration of GPM Mission Products**	**2010**

Abstract: At high latitudes, frozen precipitation and precipitation of low intensity represent the lion's share of precipitation events and a substantial contribution to annual precipitation totals. Unfortunately, the existing precipitation gauge records should be bias-corrected and in high latitudes these corrections might be as high as 100% of measured totals and, what is more discouraging, measured precipitation might be
overestimated too due to blowing snow events and misinterpretation of numerous low amounts of rainfall/snowfall that are below the sensitivity and/or precision thresholds of existing precipitation gauges. Currently, the reliability of remote sensing precipitation measurements over land is backed by the in situ gauge network. When going northward, at high elevations, and during the cold season in mid-latitudes, this support becomes "less adequate" due to increasing uncertainties of this backup network reports. Therefore,
future products of the GPM Mission may be compromised across all cold regions if they do not use for calibration the best possible in situ updatable data set over the northern extratropics with daily or better time resolution together with a comprehensive assessment of precipitation measurements accuracy, bias treatment, and representativeness. **To deliver such data set for the**

NASA Precipitation Science
Research Team is a major objective of this proposal.

Approach. Firstly, we shall pull available synoptic and precipitation data sets for the northern extratropics (the data of more than 8,000 stations) and re-process them to secure bias-correction and proper treatment of low intensity precipitation measurements. This is a laborious step because correction of each precipitation record requires a lot of supplementary synoptic information and site metadata. Thereafter, we shall:

_ Organize an orderly update of existing synoptic and precipitation datasets for the period sufficient for the GPM calibration effort to be completed; first of all, this will be done for the United States, Canada, Russia, and Belarus where the Research team members have a direct access to national archives, data collection streams, and quality control efforts.

_ Conduct the random error level assessment of point precipitation measurements for different weather conditions, precipitation gauge design, and observational practices after application of all bias corrections. This will be done using the entire historical period of record of our data holdings with particular foci on long-term field sites data comparisons in the vicinity of modern high precision sites such as the U.S. Climate Reference Network and its expansion to Russia and Canada.

_ Following the theoretical approach developed by Kagan (1997) and using the results of the previous step (that provide necessary parameters for this step), we shall conduct the representativeness studies for point precipitation measurements for different types of terrain and precipitation events at high and mid-latitudes. At this step, we shall not try to assess representativeness of the in situ precipitation network for large territories and/or watersheds. Instead, we shall focus on the grid cell (pixel) level of future GPM products to further quantify the ability of the in situ gauge network to be used for surface based precipitation comparison products in the high latitudes, at high elevations, and in the cold season in mid-latitudes.

Hsu, Kuolin, U. California-Irvine	**Reconstruction and Analysis of High Resolution Precipitation Dataset**	**2010**

Abstract: A long historical record of global high-resolution precipitation measurements is valuable for multiple uses. These include calibration and validation of numerical weather and climate models, improved description and understanding of energy and water cycle variations and distribution, andboth improved documentation of past hydroclimatic trends as well as improved prediction. Despite stronger evidence of hydrologic cycle intensification (IPCC, 2007), whether such intensification has been and/or will be accompanied by measureable changes in the frequency of hydrologic extremes such as floods and droughts requires long-term global precipitation observations at spatial and temporal resolutions high enough to capture these extreme events.

The availability of satellite observations has led to algorithms and precipitation data sets that provide global coverage. Leading data sets such as the Global Precipitation Climatology Project (GPCP) and NOAA's Climate Precipitation Center Merged Analysis of Precipitation are widely used. However, the resolution of these data sets – typically 2.5o (spatial) and monthly (temporal) resolutions – limits their capacity to capture and describe extreme precipitation events. High quality measurements from Low Earth Orbital (LEO) satellites in recent years have improved both spatial and temporal resolutions. For example, since 1997 the current version of the GPCP (V2.1) data includes a subset of TRMM and other LEO satellite-based 1o daily (GPCP-1DD)

data. For climatological studies, however, longer historical data at high spatial and temporal resolution for the period of pre-1997 are needed.

Researchers in the UCI Center for Hydrometeorology & Remote Sensing (CHRS) propose to produce a long (25+ years) record of high-resolution global precipitation measurements. Our main objective: within a global climatic context, to contribute to the understanding of precipitation variability at spatial and temporal scales relevant to extreme events. To accomplish our goal, we will first retrospectively process satellite-based high-resolution precipitation data going back to 1983. Then, we will assess the ability of the data set data to capture extreme rainfall events using appropriate verification techniques. The proposed product will use global GEO satellites and GPCP monthly measurements to develop a 0.25o daily precipitation data set for the region (-50 +50). Finally, we will analyze the data to investigate possible trends in intensity and frequency of extreme precipitations as well as their relationship to the local and regional temperature anomaly during the available period. The availability of a long-term fine spatial and temporal scale precipitation data set will contribute to the calibration of the next generation of high-resolution numerical weather prediction and climate models, which must address hydrologically relevant scales.

Hu, Qi (Steve), U. Nebraska-Lincoln	**Development of a Northern Hemisphere Gridded Precipitation Dataset Spanning the Past Half Millennium for Analyzing Interannual and Longer-Term Variability in the Monsoons**	**2010**

Abstract: While much past proxy work has focused on the reconstruction of large-scale surface temperature patterns, there is perhaps no more societally relevant climate variable than precipitation. Yet, no comprehensive large-scale reconstructions of precipitation for the Northern Hemisphere (i.e., all of North America and Asia) have been performed spanning the past millennium. This proposed reconstruction project will use all available proxy-climatic records spanning the last 500-2000 years in the Northern Hemisphere to develop: 1) gridded seasonal and annual precipitation datasets for North America, Europe and Asia with various spatial resolutions and dataset lengths, and 2) a 2.5ÅãÅ~2.5Åã latitude and longitude annual (and/or summer) precipitation dataset of the last 500 years for the Northern Hemisphere. The proposed reconstruction activities will make use of two different Climate Field Reconstruction (CFR) techniques, in particular, the regularize expectation maximization algorithm ('RegEM'), and the multivariate principal component ('PC') method, to establish results that are both skillful and robust with respect to the details of the statistical methodology.

The gridded precipitation datasets will be interpreted in the context of climate dynamical mechanisms responsible for interannual to centennial timescale variability in different regions and continents over the past 500-2000 years. Specific emphasis will be placed on understanding the potential roles of the Asian and North American monsoons, and climate modes such as the El Nino/Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), and the Atlantic Multidecadal Oscillation (AMO), in past variations in precipitation and drought. Particular attention will also be paid to the relationships with past variations in temperature documented in recently published reconstruction efforts.

One key outcome of the proposed research is a better knowledge of the natural range of precipitation variation, and its relationship with larger-scale climate dynamics, for policymakers and stakeholders who need to gauge societal vulnerability to variations in water on timescales of

decades to centuries, be it natural and anthropogenic in origin. The proposed project promises to improve the scope, both in space and time, of hydroclimatic reconstructions available for such purposes

Johnson, Richard, Colorado State University	**Legacy Atmospheric Sounding Data Set Project**	**2010**

Abstract: For more than 40 years a number of important field experiments have been conducted in the tropics and mid-latitudes in which large amounts of resources were expended to make special or intensive observations over selected locations of interest around the globe. Examples of such field campaigns are ATEX, BOMEX, GATE, MONEX, TAMEX, OK PRE-STORM, AMEX, TOGA COARE, SCSMEX, NAME, and AMMA. The data from these field campaigns have been invaluable as the main observation bases for advancing tropical, monsoon, and mid-latitude research in the last four decades, much of it involving processes associated with deep convection. These data sets were collected and used by various organizations and research groups and their archival status varies from one field program to another since no consistent data management strategy was applied. Researchers who wish to access these data often have to contact a variety of places to obtain the data (if it is even easily accessible). With the passage of time there is a certain danger that some or many of these data will be difficult to find or even lost, especially as "corporate memory" of such data status slowly fades away.

The component of field program data sets that tends to have the greatest long-term value to the scientific community is the atmospheric vertical profile represented by upper air sounding data. These observations are used most commonly for diagnostic studies for the development of cloud parameterizations for weather and climate models, and calibration and validation of independent datasets. Many of these data are also used in special model reanalysis efforts. Upper-air datasets from field programs are generally of higher quality because the large suite of instruments deployed in these field campaigns allows for cross-calibration that can greatly enhance data accuracy.

Unfortunately, there is currently no central location for access of all research-quality sounding data from past national and international field experiments. NCAR has holdings from most recent experiments, but collections from older experiments are incomplete. From what we can tell so far, sounding data for many of these older experiments do not reside at NOAA's National Climatic Data Center (NCDC), but efforts are underway to determine the extent of these archives.

It is proposed that NCAR will collaborate with the Colorado State University (CSU) Department of Atmospheric Science to undertake a data stewardship effort to:
(1) Identify past field programs for which central collections of sounding data do not exist,
(2) Track down existing holdings of sounding data for those field programs, to the extent they exist, at centers, laboratories, and universities,
(3) Extract sounding data that are found from old storage media (i.e., 9-track tapes, printouts, etc.), and place into a consistent, common digital format,
(4) Carry out standard quality control of the sounding data including objective gross limit and vertical consistency checks, and
(5) Prepare a catalog and a central, publicly

LeGrande, Allegra, Columbia University	**Sensitivity of Climate Variability to Anthropogenic and Natural Drivers during the Last Millennium**	**2010**

Abstract: The degree and causes of climate variability during the last two millennia remain poorly understood. The interactions between forcings and intrinsic variability are complicated, and the proxy records of climate response are by definition indirect measures. An ensemble of millennial-length simulations with the Goddard Institute for Space Studies GCM (ModelE) is proposed to identify regional and temporal climate "fingerprints" from potentially important forcing mechanisms. In addition, the model's Earth System components (chemistry, aerosols, water isotopes, and wetland methane emissions) will be included in time-slices of particular interest – such as the early medieval (MT, 1000-1200) or Maunder Minimum (MM, 1550-1750).

We propose a suite of coupled atmosphere-ocean model experiments from 850 AD to 1850. First, a simulation including solar, volcanic, orbital, and greenhouse-gas forcings, landuse changes, will be completed. This experiment will directly link in with other pre-Industrial experiments being completed as part of IPCC AR5 – using the same model and resolution as IPCC AR5 experiments – and it will be submitted to the PMIP3 last millennium program. Next, six ensembles of 5 members each will be performed to assess the relative impact of each of the climate forcings. Simulations include amplification of solar effects through a stratospheric ozone response. Global mean trends in surface temperature are expected to have a clear forced component, though internal variability will also have a large role, particularly at the regional scale. Previous work by this group (e.g., Shindell et al., 2001b; Shindell et al., 2004a) and data analyses have indicated that there may be a significant annular mode response to some forcings. The proposed experiments will be used to determine the magnitude of the predictable signal at regional scales over multi-centennial time periods.

Previously omitted additional forcing mechanisms will be addressed using shorter time-slice simulations with the online-tracer version of ModelE during contrasting climate periods (e.g. MM and MT), driven by saved ocean conditions from the transient experiments. Seven sets of experiments are proposed, including changes to dust, sea-salt, and ocean-derived sulfate, biomass burning ozone-precursors and aerosols, biogenic organic carbon, wetland methane emissions, and a final set with all components. These aerosol species are standard components in the model's 20th century simulations, so that we may compare millennial variability characteristics with those better constrained from more recent climate periods.

A singular value decomposition statistical technique will be applied to detect model regional and temporal variability patterns and compare with reconstructions of temperature from tree rings, ice core records, high-resolution ocean and lake sediment cores, speleothems, borehole inversions, and corals. Model variability (within and across time-slices) of polar concentrations of aerosol/gaseous species will be compared with ice core records of dust, sea salt, BC, sulfate, methanosulfonic acid, methane and water isotopes.

This project will allow identification, comparison and improved quantification of major climate forcings. Comparison of model and proxy records will test model-simulated mechanisms while the model in turn provides insight into factors contributing to proxy variability. The addition of potentially important forcing mechanisms will enable a more comprehensive evaluation of the climate sensitivity.

Lindsay, Ron, University of Washington	**A New Unified Sea Ice Thickness Data Set**	**2009**

Abstract: We propose to create a new unified sea ice thickness climate data record to better intercompare different ice thickness measurements, to better evaluate the changing state of the ice pack, and to better validate sea ice models. We would greatly improve the usefulness of these valuable data for the entire polar research community.

While ice extent is well-measured by satellite, monitoring ice thickness has been and remains a challenge. However the amount of ice thickness data available in the last few years has increased markedly, providing a large and growing resource. Existing observations of ice thickness span a variety of methods, accuracies, and temporal and spatial scales and are archived in a variety of different locations and in different formats. Each has its own strengths in terms of sampling or accuracy. The uncertainties are documented to various levels of detail for the different data sources but the documentation in general is spread throughout the literature. A concerted effort to collect as many observations as possible in one place, with consistent formats, and with clear and abundant documentation will allow the community to better utilize what is now a considerable body of observations. With a variety of data in one location and format, it will be much easier to compare the different sources with each other and with model output. The increased space and time coverage of a unified dataset will facilitate improved analyses of how and where sea-ice thickness has changed over the last three decades.

We will use data from both polar regions that are now available from moored and submarine based upward looking sonar (ULS) instruments, airborne electromagnetic (EM) induction instruments, and satellite laser altimeters (ICESat) provided to us by many different investigators. These instruments offer adequate sampling dating from 1975 to establish the mean ice thickness and thickness distribution for scales generally appropriate for change detection and climate model validations. The proposed data set will be the best approximation to a reference data set for sea ice thickness and only by using all of the available data and analyzing all of the biases will we obtain a reliable and extensive record of how the ice pack is changing.

The archive will include both the full measurements as acquired from the data providers (or links) and average values. The average values will be provide easy access for the change detection and modeling communities and will be for approximately one month of moored ULS data or 50 km of submarine, airborne, or satellite data. (Roughly 50 km or more of ice passes over a typical mooring site in a month and monthly output is commonly saved in model runs.) A web site will be created to provide easy access to the full data, the averaged data, and the documentation. We will work closely with the NOAA Arctic Research Program at PMEL to see that the data set is well publicized and we plan an EOS article to advertise the archive. The data set will be transferred to the National Snow and Ice Data Center at the conclusion of the project for permanent archival (an agreement is in place).

Linsley, Braddock, University at Albany	Coral Records of Low Frequency South Pacific Convergence Zone Variability	2010

Abstract: Decadal and century-scale variability of the Intertropical Convergence Zone (ITCZ) over the different ocean basins and continents has been documented by several studies (e.g., Linsley et al., 1994; Haug et al., 2001; Hodell et al., 2005; Sachs et al., 2009, Oppo et al., 2009) but is poorly understood. The recent results of Sachs et al. (2009) are particularly important since they confirm that over the open Pacific the mean position of the ITCZ was 500km south (~5° south) of its present position during the Little Ice Age (LIA). In the western Pacific, the South Pacific Convergence Zone (SPCZ) extends from the Warm Pool southeast to about 25°-30°S. Although the SPCZ is the largest spur of the global ITCZ, its origin and low frequency

variability remains controversial (Takahashi and Battisti, 2007b). Using coral δ18O time-series generated from Fiji, Tonga and Rarotonga on the southwestern side of the SPCZ, we have interpreted secular trends in coral δ18O to lower values in the 20th century as evidence that salinity has been dropping and surface water warming, both indicating that the SPCZ has been expanding southeast since the end of the LIA in the late 1800s (Linsley et al., 2006). This hypothesis is consistent with the Sachs et al. (2009) results for the ITCZ and suggests that during the end of the LIA, both the ITCZ and the SPCZ were equatorward of their present mean positions

We hypothesize that the 25-35 year lag in the initiation of the trend toward lower δ18O in the late 1800s at Tonga (relative to the start of the δ18O trend at Fiji) is the result of the expanding SPCZ footprint as the salinity front on the edge of the SPCZ shifted southeast. To test this hypothesis we propose to analyze δ18O and Sr/Ca on subseasonal resolution samples in coral cores collected in 2004 from Vanua Baluva at 178°56'W in far eastern Fiji in between the main Fiji Islands at 179°E and Tonga at 174°W. These new δ18O and Sr/Ca records from Vanua Baluva will allow us to evaluate the climatic significance of secular trends in both tracers in this region. If the timing of the δ18O trend at Vanua Baluva is intermediate between that observed in Fiji and Tonga this would support our hypothesis for SPCZ expansion.

Mears, Carl, Remote Sensing Systems	**Detecting Anthropogenic Changes in Atmospheric Temperatures in Microwave Sounder Measurements Using Multi Model Fingerprint Techniques**	**2008**

Abstract: Previous detection and attribution studies performed on satellite measurements of atmospheric temperature have relied on methods that employ one or at most two climate models. The models are used to generate a "fingerprint" of anthropogenic change, and this fingerprint is then searched for in the satellite observations. Such investigations have claimed successful detection of significant anthropogenic changes in tropospheric and stratospheric temperatures. It is not clear whether the findings of these studies are overly dependent on the specific behavior of the model used in the analysis. Such questions can be addressed using a true "multi-model" detection and attribution analysis, in which pooled data from many different climate models is employed for both fingerprint estimation and for estimating the noise of natural internal climate variability, and differences between simulated changes in each model are used to estimate model uncertainty. Multi-model analyses should produce more robust and credible detection results. We propose to calculate fingerprints of anthropogenic change using the pooled data from nearly two dozen climate models. A large number of model simulations of the 20th century climate were performed in support of the IPCC AR4 report. We propose to use the output from these runs to calculate multi-model fingerprints of anthropogenic change. We will also analyze the pooled information from multiple model control runs to obtain information on the amplitude and structure of natural internal variability.

The model fingerprints will be searched for in the multi-decadal records of atmospheric temperature in four layers from the lower troposphere to the lower stratosphere, constructed from microwave sounding measurements made by the MSU/AMSU series of instruments. Optimal fingerprinting techniques will be used to determine whether the correspondence between the modeled and observed patterns of temperature change could be due to internal variability alone. Data from so-called "single forcing" runs performed with several different climate models will be used to estimate the contributions of different forcing agents to the detected temperature

changes.		
Mears, Carl, Remote Sensing Systems	**Monitoring Stratospheric Climate Change Using AMSU**	**2009**
Abstract: Historically, satellite measurements of the stratospheric temperatures have been made by the Stratospheric Sounding Unit (SSU), an infrared sounder, and (for the lower stratosphere) channel 4 of the Microwave Sounding Unit. The follow-on instrument to MSU, the Advanced Microwave Sounding Unit (AMSU) monitors additional microwave channels that extend to the upper stratosphere, covering the range of heights measured by SSU. In order to continue to provide climate-quality monitoring of the stratosphere, these channels need to be investigated to ensure that they are stable enough for climate applications, and adjustments need to be made to account for changes in measurement time and any other sources of drift that are uncovered. It is important to continue to monitor stratospheric temperatures over the next decade because stratospheric ozone is expected to begin to recover, and to test future climate models, which are tending to include more features of the upper stratosphere and mesosphere in their analysis. We proposed to perform a detailed calibration of AMSU channels 10-14 for each AMSU instruments, and to construct a merged dataset containing data from all AMSU instruments that are determined to provide high quality data. Once constructed, these data sets will be made available to the scientific community via the World Wide Web.		
Mock, Cary, University of South Carolina	**Long Daily Historical Climate Reconstructions for Southern Alaska**	**2009**
Abstract: Daily and sub-daily historical weather observations are available for southern Alaska, providing a valuable extension of the modern instrumental record back to around 1830. Much of these data have never been extracted from the archives, digitized, or have been systematically analyzed, The proposed research will extract all known meteorological data from land-based stations and ship logbooks housed at various archives. The proposed research will improve our understanding of Northeast Pacific and southern Alaska climatic variability by: 1) reconstructing interannual and decadal temperature and precipitation variability; 2) examining temporal changes in the relationships between major modes of atmospheric circulation (e.g., ENSO) with the Alaska temperature and precipitation reconstructions; 3) reconstructing monthly PDO, PNA, and CNP (Central North Pacific Pressure) indices using Alaskan data along with other high quality daily nineteenth century data from the West Coast and Southeast U.S.; and 4) reconstructing major extratropical storms and relating the temporal variations with forcing mechanisms of climatic change. The historical data, much of it sub-daily in temporal resolution with as many as 18 instrumental observations per day such as recorded by Russians observers at Sitka Alaska, will enable the Northeast Pacific Ocean and southern Alaska to have the most detailed and longest homogeneous high resolution nineteenth century climatic records for North America.		
Nicholson, Sharon, Florida State University	**Examining the 19th Century Record of Sahel Rainfall in the Context of Global Change**	**2008**
Abstract: This proposal examines climatic variability over West Africa during the 19th century, using a semi-quantitative data set developed by the P.I. This data is produced from a combination of documentary information and gauge data. Rainfall is characterized by a value ranging from -3 to +3. Although only semi-quantitative, this data set readily lends itself to simple		

statistical analyses, including spectral analysis. Using this data set, we compare rainfall variability in the historical (i.e., 19th-century) and modern records. In doing so, we consider both detection and attribution of climate change in the region. The proposed work should provide a better foundation upon which to determine whether the long decline in Sahel rainfall is a consequence of global warming.

Norris, Joel, Scripps Institution of Oceanography; Evan, Amato, U. Virginia	**Multidecadal Cloud Variabilty and Climate Change in Observations and CMIP5**	**2010**

Abstract: Cloudiness plays a key role in the climate system due to its large radiative impact, but it is currently not known how clouds will change with global warming. Several key uncertainties noted by the IPCC AR4 are: 1) how cloud cover has changed during the past several decades of surface and satellite observations, 2) how cloud cover is projected to change with increasing greenhouse gas concentrations in climate models, and 3) the sign and magnitude of cloud feedback on climate. There are several reasons why answers to these critical questions are unknown. Satellite cloud records suffer from inhomogeneities due to insufficient calibration, orbital drift, sensor degradation, etc. These problems are currently so bad that decadal variability in the observational record is predominantly spurious. The surface cloud record from ICOADS exhibits a suspicious spatially uniform increase in cloud cover over almost the entire ocean, but the origin of this apparent artifact is not known. Because AR4 global climate models incorrectly and inconsistently simulated cloudiness, exhibited severe biases, and produced cloud trends of differing signs across different models, it was difficult to produce a credible projection of expected cloud changes in future decades.

In the proposed project, we will use cluster techniques to identify artifacts in the ISCCP satellite cloud dataset. Satellite view angle and geostationary calibration artifacts will be empirically removed by appropriate linear regression. A newly calibrated and newly processed ISCCP dataset will become available in the next year, and it is expected that physically-based recalibration of ISCCP will provide even better results. We will determine whether artifacts remain in the new ISCCP, and if so, apply empirical adjustments to remove them. The diurnal cycle of cloud from ISCCP will be used to physically correct the PATMOS-x satellite cloud dataset for the effects of orbital drifts through local time that aliased the diurnal cycle into long-term trends. We will also investigate and remove artifacts in ICOADS surface cloud reports to extend the observational record into the pre-satellite era. Our goal is to obtain three independent and homogenized cloud datasets derived from ISCCP, PATMOS-x, and ICOADS that will provide a reliable measure, including an uncertainty range, of long-term variability in global and regional cloudiness during the past several decades. These datasets will be archived for use by the general community.

Our homogenized cloud record will then be used to investigate multidecadal cloud variability from the new and improved generation of global climate models in CMIP5. We will examine projected 21st century CMIP5 cloud changes that are common across many models to see if they are consistent with plausible projected meteorological changes (and therefore more likely to be robust). Observed cloud changes that resemble projected cloud changes may be attributed to anthropogenic global warming if they rise above the level of natural variability suggested by the models and observations. Our plan is to finish the research and publish our results in time to be included in the upcoming IPCC AR5.

Notaro, Michael, University of Wisconsin	**Observed and Simulated Trends in Heavy Lake Effect Snow Events Across the Great Lakes Basin**	**2009**

Abstract: We propose a combined observational and modeling analysis, focusing on the detection and attribution of trends in heavy lake effect snowstorms across the Great Lakes Basin. These extreme events impose a substantial economic and social toll, including fatalities and injuries, loss of power, transportation immobilization, vegetation die-off, and structural collapses. While an increasing focus has been given to extreme events in recent years, extreme lake effect snowfall remains largely unexplored, both in observations and model prediction studies.Observational data suggests that lake effect regions experienced an increase in total snowfall during the 20th century, but it is unclear if heavy lake effect snowstorms have become more abundant. We will develop a climatology of observed extreme lake effect snowstorms in the Great Lakes Basin and assess observed trends in their occurrence.

It is likely that future climate change, related to rising concentrations of greenhouse gases, will result in changes in the frequency and intensity of heavy lake effect snowstorms. The latest IPCC Assessment Report includes an array of state-of-the-art global climate model predictions, yet these models either fail to represent the Great Lakes or significantly underrepresent them. We propose to use two regional climate models (differing only in cumulus parameterization) with 20-km horizontal grid spacing, driven by the large-scale fields of several IPCC AR4 global models, to predict future trends in heavy Great Lake effect snowstorms in a probabilistic trend analysis. The regional model will be interactively coupled to a onedimensional thermal eddy diffusion lake model, allowing for the simulation of lake ice. We will relate trends in heavy lake effect snowstorms to changes in ice cover, cold air masses, air-lake temperature contrast, storm tracks, atmospheric moisture, wind flow, and teleconnection patterns.

Russell, James, Brown University; Vuille, Mathias, University of Albany	**High-frequency Variations in the Indian Ocean Dipole During the Past Millennuim Reconstructed from East African and Indonesia Lake Sediment Cores**	**2009**

Abstract The Indian Ocean Dipole (IOD) is a natural mode of coupled ocean-atmosphere variability in the equatorial Indian Ocean that affects the lives of billions of people in Africa and Asia. During positive IOD events, the western Indian Ocean warms while the east cools, triggering extreme flooding and drought in East Africa and Indonesia, respectively. Observational data indicate that the IOD has varied at interannual to decadal time-scales during the 20th century, and investigations of East African paleoclimate suggest that the IOD plays a key role in past climate variability on orbital to decadal time-scales. However, reconstructions of the IOD only cover the past ~150 years, too short to investigate decadal IOD variability and its role in controlling the duration and intensity of high-frequency tropical climate variations.

We propose to reconstruct decadal variability of the Indian Ocean Dipole during the last millennium by producing new, high-resolution, multi-proxy reconstructions of rainfall and its isotopic composition from sediment cores from lakes in tropical East Africa and Indonesia. This research takes advantage of recent findings in climate modeling, stable isotope climatology, organic geochemistry, and fieldwork in East Africa and Indonesia that have: A) Shown that East Africa and Indonesia experience large and antiphased changes in the isotopic composition of rainfall (δprecip) during Indian Ocean Dipole events; B) Demonstrated that long-chain fatty

acids preserved in lake sediment record the isotopic composition of regional precipitation, providing direct insight into the atmospheric processes governing rainfall, and C) Provided a unique set of new, often laminated, sediment cores from lakes in East Africa and Indonesia with extremely rapid sedimentation rates, ideal for the high-resolution analysis proposed here.

We propose to generate new, decadal-resolution records of δprecip from East Africa and Indonesia by applying proven organic geochemical tools of hydrogen isotopic analyses of organic biomarkers (specifically terrestrial leaf waxes to radiometrically-dated sediment cores from multiple lakes in East Africa and Java, Indonesia. Our new datasets will be directly compared to assess antiphased variability in the IOD's two centers of action, providing a direct reconstruction of decadal variability in δprecip related to the IOD and climate in these two regions. We will investigate and calibrate these records through both empirical comparison to IOD indices during the late 19th and 20th century, and using simulations from isotope-enabled climate models to generate a millennium-long, decadally resolved record of the IOD.

This research intersects several areas of emphasis of the NOAA paleoclimatology program. Our overarching goal is to extend the observational record of the IOD across the past 1,000 years to investigate its long-term variability, trends, and its role in controlling extreme, decadal-scale rainfall events in tropical East Africa and Indonesia. This work will advance our understanding of 'natural modes of variability and their role in historical extreme events' in two densely inhabited regions with economically vulnerable populations. Our work will also test the ability of models to simulate forced and unforced changes through comparisons of simulations from isotope-enabled general circulation models to our reconstructions.

Sachs, Julian, University of Washington	**Tropical Pacific Climate Variability During the Last Millennium from Sediments, Corals & Mollusks**	**2008**

Abstract: The climate of the last 1,000 years was punctuated by two prominent events: the Medieval Warm Period (MWP) from 1000-1300 A.D. and the Little Ice Age (LIA) from 1400-1850. The impact of, and evidence for these events derives almost exclusively from the middle latitudes of the Northern Hemisphere continents, largely from tree rings (Jones & Mann, 2004) and mountain glaciers (Grove, 1988). Remarkably little attention has been given to the tropical climate of the last millennium and its potential impact on the middle and high latitudes even though massive fluxes of latent heat, moisture and momentum originate there (Peixoto & Oort, 1992). Indeed, records of the ENSO system, the monsoons of Asia and India, and the position of the Intertropical Convergence Zone (ITCZ) indicate that the last 1,000 years were a time of profound changes in the tropical climate globally. During the LIA the East Asian (Wang et al., 2005) and Indian (Anderson et al., 2002) monsoons plumbed their weakest intensity and, at least regionally, the ITCZ reached its southern-most position of the entire Holocene (Haug et al., 2001; Newton et al., 2006), ENSO intensity and frequency may have been higher than any time in the last 1,000 years (Cobb et al., 2003), and the Gulf Stream transport may have declined by 10-15% (Lund et al., 2006).

More recently, the intensity and frequency of El Niño events appears to have increased during the last 25 years relative to the prior 110 years. Judging whether this recent increase in El Niño activity is historically significant or within the normal range for the last millennium is still not possible owing to a scarcity of climate time series longer than 150 years. Indeed, most instrumental records of temperature and rainfall from the tropics are much shorter than that, and are often on the periphery of the tropical Pacific Ocean where rainfall and temperature are

influenced by monsoon circulations and continental climates. In order to evaluate with confidence whether the more frequent and intense El Niño events of the last 25 years are anomalous relative to the last thousand years—a period sufficiently long to include forty 25-year intervals, plus the Little Ice Age and Medieval Warm Period--we propose to extend the record of tropical Pacific climate back to 800 A.D. using marine and lake sediments, corals, and mollusks to produce a robust record of the mean state of the tropical Pacific and variations in ENSO against which the changes of the recent decades can be rigorously evaluated.

The focal point of our approach is to reconstruct climate on time scales from 10^{-1} to 10^{2} yr across the entire tropical Pacific, 135°W to 80°E and 20°S to 20°N, using multiple sites, archives and proxies from Palau, Papua New Guinea and northeast Australia in the west, the Northern Line Islands and Tahiti in the center, and the Galapagos, Clipperton Atoll, and Peru in the east (Fig. 1). We will combine records of seasonal, annual and inter-annual climate variations from mollusks (by Dr. Matthieu Carre, a JISAO Postdoctoral Fellow in my laboratory) and corals (by Dr. Sandy Tudhope at the University of Edinburgh and Dr. Janice Lough of the Australian Institute of Marine Science) with records of inter-annual, decadal and centennial climate variations from sediments. We believe this multiple-archive, multiple-proxy approach across a wide swath of the tropics is the only way to produce climate time series of sufficient temporal and spatial resolution to meaningfully test and help improve models that are being used for predicting the response of ENSO and the global climate to increasing greenhouse gas forcing.

Our study is thus motivated by the following hypotheses:

1. Tropical climate reached extremes during the last millennium unmatched during the rest of the Holocene.
2. Tropical climate changes of the past millennium are linked with, and may have been drivers of significant regional and hemispheric changes in Northern Hemisphere air temperature that occurred during the MWPLIA period.
3. The 17th century marked an inflection point during the last millennium for the position of the ITCZ (southern-most), the Asian and Indian monsoons (weakest), and ENSO (most intense and frequent).

In order to test these hypotheses a robust climatology is required that spans the entire tropical Pacific Ocean and extends back in time to 800 A.D. This proposal seeks to produce that product.

This project addresses the scientific objectives of the "Climate Change Data and Detection-Paleoclimatology" element of the NOAA Climate Program Office. Specifically, we will produce a robust record of ENSO and the climatic mean state of the tropical Pacific since 800 A.D. by applying multiple proxies in multiple archives that have monthly-to-decadal resolution in those regions most strongly impacted by El Niño. Thus this project will provide an urgently needed data product that the climate modeling community can use for validation purposes. Finally, it will provide a sound basis for evaluating whether the late 20th-century increase in the strength and frequency of El Niño events is anomalous. All data generated from this project will be archived at the Paleoclimatology Branch of the National Climatic Data Center (NCDC).

Sheffield, Justin, Princeton University	**Improved assessment of historical and future projected changes in global and regional drought**	**2010**

Abstract:

Introduction to the Problem: In the U.S., the annual cost of droughts is about $5-8B. Globally, drought (and flood) losses have increased tenfold over the second half of the 20th

century, to $300B. This is partly due to increases in population and wealth but may also be due to an increase in the number and severity of events that is only likely to get worse, given future climate projections. Detecting changes in extreme hydrologic events and their future risk relies on robust historic estimates of their occurrence. In its evaluation of changes in historic global drought, the latest IPCC Assessment Report (AR4) draws heavily from global analyses of the Palmer Drought Severity Index
(PDSI), a simple modeled surrogate for soil moisture that is a popular drought monitoring tool. The PDSI shows a global decrease (increase in drought) in the last few decades that is attributed to global warming. However, the PDSI has a number of shortcomings because of its simplicity, which impact the depiction of trends. Of particular concern is its treatment of potential evaporation (PE), which is modeled as a function of temperature only and thus responds to recent observed warming, yet PE is also controlled by radiation, humidity and windspeed. A more realistic representation of evaporation
is given by the Penman-Monteith (PM) algorithm, which accounts for both radiative and advective processes. Studies have shown that using the PM in calculations of PDSI at sites across Australia dramatically changed the trends in drought, which were sometimes of a different sign, mainly a result of decreasing windspeed. Our initial global simulations indicate how this effect manifests itself globally, with the decreasing trend in the original PDSI (and corresponding increase in drought) not apparent when using the PM formulation.

Rationale: These initial results show that the current IPCC assessment of global increase in drought is likely overestimated because of the reliance on a simplified model of drought that is over-sensitive to changes in temperature. Nevertheless, it is unclear what the true trend in drought is and whether increases in precipitation or other changes, such as increased snow melt, have offset the direct temperature effect. Given the wide-ranging policy impacts of such an overestimation and the remaining uncertainties, it is imperative that more robust estimates are made. We propose to evaluate the robustness of current estimates of changes in 20th century drought occurrence and develop improved datasets based on observation-forced, state-of-the-art hydrologic modeling, including the uncertainties, and use these to evaluate climate change projections. In particular we will focus on making robust estimates of 20th century global drought, and evaluate recent changes within the context of global warming and hydrologic cycle intensification. This work will leverage from the climate dataset development, global modeling and historic and future drought analyses carried out by the PI. These analyses have been cited in the recent 3rd UN World Water Development Report and the forthcoming FY2010 USGCRP report to Congress.

Summary of work to be completed: 1. Evaluate the possible overestimation of global drought trends by the PDSI by comparison with more comprehensive estimates from observation forced hydrologic modeling. 2. Make improved estimates of historic drought based on our hydrologic modeling by using higher-quality regional meteorological data and extending back in time and updating to recent years. 3. Evaluate the uncertainties in drought reconstructions as derived from uncertainties in the climate forcings and the choice of hydrologic model. 4. Analyze these datasets in terms of changes in the occurrence and characteristics of drought and attribute change to the climate forcings and changes in the hydrologic cycle. 5. Evaluate CMIP5 simulations of historic drought and future projections against our hydrologic model based estimates and make improved projections through bias correction and downscaling.

Soden, Brian, University of	**Development of a Long-Term, Homogenized**	**2010**

Miami	**Upper Tropospheric Water Vapor Data Set From Satellite Microwave Radiances**	

Abstract: All climate models predict that the atmosphere will moisten in response to increasing greenhouse gases. The concentrations of water vapor in the upper troposphere are projected to double by the end of the century. This amplified moistening aloft not only represents a key feedback mechanism, but also provides an important fingerprint for the detection and attribution of climate change.

Previous funding from the NOAA CCDD program supported our efforts to construct and validate an intercalibrated and drift-corrected data set of satellite *infrared* radiances from HIRS/2 for the period 1979-2004. This product was the first record to show an increase in upper tropospheric water vapor on decadal time-scales consistent with a positive water vapor feedback and also yielded the first observational evidence of an enhanced clear-sky greenhouse effect due to human activities.

In this proposal we seek to expand our efforts to utilize the growing archive of satellite *microwave* measurements from SSM/T-2 (1994-present), AMSU-B (1998-present), MHS (2003-present) to construct a long-term homogenized data set of upper tropospheric water vapor. Because microwave measurements are less affected by clouds compared to infrared measurements, the water vapor data set derived from these measurements will have improved space/time coverage and be less prone to clear-sky sampling biases. Most importantly, it will continue the long-term monitoring capabilities of upper tropospheric water vapor which ended for HIRS/2 in 2004.

Specific tasks to be completed under this proposal are:

• Develop orbital drift corrections to the microwave radiances from each satellite sensor to remove the effects of orbital drift on the long term radiance trends.

• Use simultaneous nadir overpasses (SNO) to intercalibrate the microwave radiances to create individual calibrated records for each satellite system.

• Create an upper tropospheric humidity (UTH) product from the intercalibrated microwave radiances to facilitate the analysis of water vapor variations and trends.

• Compare to the microwave satellite measurements to climate model simulations from the CMIP5 archive to assess the ability of models to simulate the observed variability and to determine if any of the observed changes can be attributed to human activities.

The proposed work will address the FY 2010 priority of creating a 'long-term continuous record,' of atmospheric data and the results will be used to evaluate the fidelity of water vapor changes simulated in CMIP5 GCMs.

Stahle, David, University of Arkansas	**Millennium-Long Reconstructions of Cool and Warm Season Precipitation Over the Southeastern and Southwestern United States**	**2008**

Abstract: Some of the longest and most climate sensitive tree-ring chronologies in the world have been developed from arid-site conifers in the southwestern United States and from swamp-grown baldcypress in the Southeast. These chronologies have been used to reconstruct precipitation, streamflow, Palmer drought severity indices (PDSI), and the larger-scale ocean-atmospheric forcing of interannual climate variability over North America. Ironically, however, most of these annual ring width chronologies integrate the effects of precipitation and

temperature during the winter, spring, and early summer, and do not provide a simple proxy for summer precipitation. The integration of cool and early warm season precipitation is ideal for the estimation of the long-term soil moisture balance as embodied in the PDSI, but annual ring width cannot resolve separate cool and warm season precipitation totals nor the distinctive modes of atmospheric circulation responsible for interannual and decadal variability in each season. The annual growth rings of many conifers (e.g., Pseudotsuga menziesii, Pinus Ponderosa, Taxodium distichum) exhibit a distinctive anatomical transition from earlywood (EW) to latewood (LW) that segments the annual ring into the components formed in the spring and summer. These exactly-dated components of the annual ring can be precisely measured and separately calibrated with winterspring and summer precipitation. The proposed research will re-analyze existing tree-ring collections from the Southeast and Southwest to derive separate millennium-long reconstructions of cool and warm season precipitation. The proposed reconstruction will be used to document seasonal precipitation regimes during megadroughts and pluvials of the past millennium, test the frequency modulation of the seasonal reconstructions at ENSO, decadal, bi-decadal, and multidecadal timescales, analyze the evolution of these important frequency components in seasonal precipitation from the Medieval era to Little Ice Age and into the modern period of anthropogenic climate change. In and out-of-phase anomalies in seasonal precipitation between the southeast and southwestern United States have been linked to longwave circulation regimes over North America and to solar irradiance changes in GCM simulations, and will be investigated on interannual to multidecadal time scales. The reconstructions will also be used to investigate the conditional predictability of warm season precipitation based on anomalies reconstructed during the preceding cool season, as has been hypothesized for monsoon onset over the Southwest based on preceding cool season precipitation. The proposed seasonal precipitation reconstructions will provide a more complete description of droughts, megadroughts, and pluvials over the southeastern and southwestern United States for the past millennium, and will provide key empirical data need to test dynamical explanations of natural and anthropogenic climate change. The proposed seasonal reconstructions will frame the current and predicted aridity trend over subtropical North America in the context of natural variability and will be relevant to regional and federal water and energy policy.

Stott, Lowell, U. Southern California	**Is the current drought affecting the Western US unique from earlier droughts of the 20th Century and therefore attributable to anthropogenic climate change?**	**2010**

Abstract: Our proposed research seeks to assess whether or not the drought currently affecting the western US is distinguishable from previous droughts during the 20th century. Climate model simulations forced with anthropogenic greenhouse gases predict decreased P-E over the southwestern US during the 21st century in response to a combination of mean humidity change, change in the mean circulation and changes in eddy circulation behavior. It is not yet clear which of these factor(s) accounts for the present drought. Previous droughts during the 20th and pre-20th century have been attributed to anomalously cool, La Niña SSTs in the tropical Pacific and multi-decadal temperature variability in the North Pacific associated with the Pacific Decadal Oscillation. The current drought has persisted in the absence of La Niña conditions, which raises the question of whether it is due in part to anthropogenic forcing.

In previous studies we suggested that northward-southward shifts in storm tracks along

the west coast of the US occurred repeatedly during the past millennia and that these shifts are documented in the isotopic mass balance of the annual precipitation that is a mixture of tropical/subtropical and extratropical water vapor sources (Berkelhammer and Stott, 2009; Berkelhammer and Stott, 2008). Our initial findings were based on d18O measurements of cellulose extracted from the annual rings of long-lived trees in California, which derives its isotopic composition from rainwater and local humidity and temperature. We suggested that as mean storm trajectories shifted southward, precipitation incorporated proportionally more subtropical moisture, which is isotopically more enriched. This isotopic enrichment is transferred to cellulose of annual tree rings. Our findings documented a close correspondence between drought and decreased tropical/subtropical moisture convergence over the southwestern US during the 20th century. In other words, previous droughts over the southwest were accompanied by a northward shifts in mean storm tracks. We do not observe a similar isotopic shift in association with the current drought.

The study proposed here would create a database of annual cellulose and rain water d18O from a suite of locations along the west coast spanning the 20th century and combine this with a newly developed isotope-enabled global climate model-derived reanalysis product. With these results we will quantitatively calibrate isotopic variability of precipitation against explicit climate variability over the 20th century in a way that was hitherto not feasible. In doing so, we will reconstruct changes in moisture source variability and storm track behavior that influenced the regional water balance with a particular focus on water source variations at the onset, peak and end of multi-year drought and times of short-lived ENSO-related drought and pluvials. At the completion of the three year project we will have developed a new well-calibrated 20th century isotope reanalysis product, extending the late 20th century products of Yoshimura et al., (2008) through the early 20th century. The results of this study will provide an independent test of how the current drought compares to previous droughts and provide an isotopic reanalysis product that can be used by others in the interpretation of paleo-hydrologic proxies. This collaborative endeavor brings together the experience of Lowell Stott and Max Berkelhammer of USC in isotopic measurements and data analysis with Kei Yoshimura of Scripps Institution of Oceanography (SIO) who has developed the isotope-enabled GSM.

Timmermann, Axel, University of Hawaii	**Changes in the Tropical Pacific Climate Variability During the Last Millennium: External Forcing Versus Internal Variability**	**2008**

Abstract: Paleo proxies, documentary research and instrumental data, all capture variations in ENSO behavior over the past centuries and throughout the Holocene. Much of this variability appears to be internal to the earth's climate system, but there is evidence from intermediate coupled models and coupled general circulation models that orbital variations have been responsible for systematic changes of ENSO statistics throughout the Holocene. Recently, also volcanic aerosol forcing as well as changes in the solar irradiance have been suggested as potential drivers for low-frequency changes of ENSO. Separating externally forced signals in tropical Pacific climate reconstructions and model simulations from the ones that are generated by internal instabilities is a fundamental problem, which will be addressed in our proposed research. Using several existing climate model simulations of the last 500-1000 years, we will elucidate the physical mechanisms responsible for long-term changes of tropical Pacific climate during the last millennium. Questions to be addressed specifically are:

• What is the degree of consistency between different paleo-ENSO reconstructions during the

last millennium?
• What is the range of internally generated ENSO variability on decadal and centennial timescales
in comparison with the externally-induced low-frequency modulation of ENSO?
• What are the mechanisms of internally generated and externally-induced long-term changes of ENSO?

These questions will be addressed by a careful statistical analysis of existing paleo-proxy data for ENSO and by using coupled-atmosphere ocean general circulation model simulations for the last 500-1000 years.

Our proposed research will reassess existing paleo-proxy data, provide rigorous uncertainty estimates, and might eventually contribute to a better understanding of ENSO's sensitivity to climate change, with important implications for society.

Ting, Mingfang, Columbia University	**Understanding and Attributing Tropical Cyclone Intensity and Frequency Changes in the 20th and 21st Centuries**	**2010**

Abstract: We propose to provide a quantitative assessment of the role of forced versus natural SST variability on hurricane intensity and frequency changes in both the 20th and 21st Centuries, based on observational records as well as CMIP3 model simulations. The key hypothesis is that naturally varying and forced components of SST have distinctively different influences on tropical cyclone potential intensity and genesis potential index (related to hurricane frequency) that may explain the discrepancy in observed trend versus model projections of changes in hurricane intensity and frequency. The ultimate goal is to provide a better understanding and prediction of future changes in tropical cyclone intensity and frequency.

The change in intensity and frequency of tropical cyclones as a result of green house warming is a topic of great societal concern due to the disastrous nature of these storms. Recent observational studies based on the satellite era Atlantic hurricane records have shown a robust upward trend in Atlantic hurricane intensity. While many have argued for an increase in tropical cyclone intensity in the warming world due to the increasing SST, the actual projection of the potential intensity (PI), a theoretical upper limit of the cyclone intensity, of tropical cyclones based on CMIP3 models' 21st century simulations have not shown a consistent upward trend. The discrepancies are possibly due to the fact that both local and remote SST could contribute to the PI and the relative warming of the local SST may be more relevant in determining the PI, as previous studies indicated. We propose in this study to understand further the relation between SST and tropical cyclone PI by decomposing the effect of anthropogenically forced and the naturally occurring SST variability. Regarding hurricane frequency, there has been an upward trend in the Atlantic since 1980. However, recent model projections for Atlantic hurricane frequency are pointing towards a reduction of hurricane frequency under the 21st century conditions. A similar calculation to that of the PI will be applied using an empirical genesis potential index (GPI) as a measure of tropical cyclone frequency. The results of the study will help a more accurate projection and better understanding of the future frequency and intensity change in tropical cyclone activity based on model simulations and observations of the tropical SST variability.

Vose, Russell, National	**Development of HadEX2: Gridded Indices of**	**2010**

Climatic Data Center	Climate Extremes	

Abstract: In this project, we propose to produce high quality, globally consistent, gridded datasets of long-term observations of climate extremes with uncertainty estimates, updated in near-real time for monitoring purposes and freely available to the public. We will then use the gridded fields to examine long-term changes in extremes and to assess the representativeness of climate model simulations. The work is expected to make a significant contribution to the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report. The gridded datasets will be commonly referred to as HadEX2.

HadEX2 will be based on a number of large daily and sub-daily datasets that are currently available. The premier example is the National Climatic Data Center's (NCDC's) Global Historical Climatology Network (GHCN) – Daily dataset, which contains over 20,000 temperature and 40,000 precipitation stations. Another is NCDC's Integrated Surface Dataset, which contains subdaily observations for approximately 22,000 synoptic stations worldwide. To the extent possible, these global archives will be supplemented with various national- and regional-scale datasets that we will attempt to obtain through traditional methods. Reasonable efforts will be made to ensure the homogeneity of the station data prior to creating the gridded fields.

Several "optimal" interpolation techniques (e.g., angular distance weighting, climatologically aided interpolation) will then be evaluated for use in the development of HadEX2. To this end, we will leverage off of the experiences and methods of several ongoing efforts. One example is HadGHCND, a joint NCDC-Met Office Hadley Centre endeavor that produced (and operationally updates) daily temperature and precipitation grids for global land areas. Another is the EU ENSEMBLES project, which has created high resolution daily temperature and precipitation grids for Europe. Regardless of the interpolation method(s) ultimately selected, however, it is critical to address two questions. The first is the mismatch between the spatial representativeness of in situ extremes, which are point measurements by definition, and that of gridded climate model output, which is often assumed to represent area mean values. The second question involves the quantification of uncertainty, both statistical and structural, in the final gridded fields.

As climate changes, as a result of natural variability and anthropogenic global warming, we need to monitor extreme events. Consequently, HadEX2 will be updated operationally on a daily basis. The new software, which will incorporate homogeneity and quality control testing, indices calculation, and gridding, will be subject to version control. The output will be available in near real time from NCDC and the Met Office Hadley Centre.

Walsh, John, University of Alaska - Fairbanks	Downscaling of Climate Model Output for Alaska and Northern Canada	2010

Abstract: Statistical downscaling provides a means to bridge the gap between the coarse resolution output of climate models and site-specific climate information for which there is a particular need in the Arctic. The observational databases, model output and statistical methodologies are now available for a downscaling project targeted at Alaska and northern Canada, in collaboration with other regional Arctic downscaling projects coordinated by the Arctic Monitoring and Assessment Program. We propose a three-tiered approach to an implementation of downscaled climate projections for the North American Arctic through 2100. First, 21st-century changes projected by the IPCC Fourth Assessment models that perform best

for the Arctic will be fused with a high-resolution (2 km) climatology of Alaskan temperature and precipitation. Second, the output from the models will be adjusted by using the biases in the models' means and variances to optimize the output from the models' projections. This approach will be applied to daily as well as monthly output, allowing for the analysis of changes in extreme events. Third, existing software packages for statistical downscaling (e.g., Clim.pact, SDSM) will be implemented for Alaska and northern Canada. The Arctic's intensive observatories at Barrow, Alert and Eureka will be focal points in the algorithm development and validation. The products will be consolidated and archived with Arctic downscaling output from other Arctic countries for use in future climate impact assessments.

Wang, June, NCAR	**Homogenization of global radiosonde humidity data**	**2010**

Abstract: Humidity data from balloon-borne radiosondes provide the longest record (for the last six decades r so) with high vertical resolution and near world-wide coverage; however, its usefulness in climate studies and atmospheric reanalyses is limited, in part, by changes in sensor characteristics over time and space that often induce large spurious changes. Therefore, it is imperative to homogenize the radiosonde data before they can be reliably used for climate studies and global reanalyses. Extensive research has been devoted to homogenize global radiosonde temperature data, which have played a crucial role in reconciling differences in tropospheric temperature trends and improving atmospheric reanalysis. However, no comparative efforts have been made to homogenize global radiosonde humidity data.

The main goal of this proposal is to homogenize radiosonde humidity data from individual soundings from 1958 to present over the globe and produce a reliable humidity dataset for community use. First, we will start with compiling a comprehensive global radiosonde dataset from several different sources, including data from synoptic radiosondes and field campaigns. Second, the project will focus on developing a rigorous approach to detect no-climatic change-points in radiosonde humidity time series, including testing different variables such as dew point depression and relative humidity as well as other difference time series using various detection methods. The detected changepoints will be validated against a comprehensive metadata database generated from different sources by this project. Third, adjustments will be made to the time series to homogenize the data. This step will begin with applying physical and empirical correction methods developed for recent radiosondes (by comparing with GPS measurements, for example) to produce more accurate data for most recent years. Then statistical homogeneity adjustment methods will be used to remove the remaining inhomogeneities that could not be adjusted empirically. Fourth, both the original and homogenized data along with the metadata will be archived and distributed by NCAR and other data centers for wide community use, including applications in future atmospheric reanalysis efforts. Finally, the homogenized data will be analyzed to quantify global humidity trends.

The proposed work will produce a reliable humidity data set that will help quantify water vapor trends under global warming. Combined with the already homogenized upper-air temperature data, our humidity data will ensure that future atmospheric reanalyses will have a much improved input data set that is necessary for their applications in climate change studies.

Xie, Pingping, Climate	**Development of a 60-Year Gauge-Based**	**2010**

Prediction Center	Analysis of Hourly Precipitation for the Conterminous United States	

Abstract: Numerous observational studies have documented changes in the amount, intensity, frequency, and type of precipitation during the 20th century in the United States. Likewise, various model-based analyses indicate that the spatial-temporal distribution of precipitation may change considerably during the 21st century. Of particular note, an increased frequency in heavy rainfall events is expected over many regions, likely resulting in the more frequent occurrence of major flood events.

Long-term precipitation datasets, with appropriate time and space resolution, are required to accurately document long-term trends in extreme precipitation. Virtually all published long-term trend studies, however, are based on monthly and daily records. While such data provide some perspective on long-term changes (e.g., in drought, daily extremes), variations at the sub-daily level must be examined to truly understand the physical causes and societal impacts of precipitation extremes.

Among a number of areas identified in the Intergovernmental Panel on Climate Change Fourth Assessment Report where uncertainty is highest and additional attention required includes analysis and monitoring of extreme events including the frequency and intensity of precipitation. Specifically, longer data time-series of higher spatial and temporal were identified as a primary need for addressing this deficiency.

In this project, we propose to construct a gauge-based analysis of hourly precipitation over the conterminous United States (CONUS) for a 60-year period from 1948 to the present. We will then use the data set to examine heavy precipitation events and their long-term changes. The first step of this project will involve the creation of a baseline hourly precipitation analysis on a 4kmx4km grid over CONUS for the period 1998-present. This will be accomplished by combining Stage-II radar observations, satellite estimates (CMORPH), and gauge reports (NCDC/DSI-3240, HADS). A gauge-based analysis will be created by interpolating hourly reports from all sources. Biases in the radar and satellite precipitation estimates will be corrected through matching the probability density function (PDF) of the radar/satellite data with that of the collocated gauge data. Bias-corrected radar/satellite estimates will then be combined with the gauge analysis through the optimal interpolation (OI) technique to form the hourly precipitation analysis.

There is a twofold purpose in creating this baseline analysis for 1998-present. First, it will provide a set of criteria for selecting gauge stations in the interpolation process for the 60-year gauge-only analysis. Second, it will facilitate the quantification of network-based uncertainty in the 60-year gridded fields.

Uncertainty will be assessed by interpolating gauge reports from various combinations of available stations. The performance of these sub-networks will then be compared with the ‘truth’ (i.e., baseline analysis) to assess their quantitative accuracy, i.e., their ability to:
a) represent hourly precipitation as a function of precipitation intensity, network density, calendar season, geographic location, and size of averaging domain;
b) capture extreme events as measured by the fidelity of the PDF of area-averaged precipitation intensity over a grid box; and
c) identify biases and aliases in long-term changes in the frequency and spatial distribution of extreme events caused by insufficient networks (and changes therein).

The uncertainty assessment will then be used to guide the development of the gauge-based analysis of hourly precipitation for the full 60-year period. Gauge reports will be selected from

the NCDC/DSI-3240 data set. The grids themselves will be created by interpolating selected station reports through an OI-based objective analysis algorithm with consideration of orographic effects (Xie et al., 2007). An estimation of random error will be included for each grid box and for each hourly precipitation analysis. Seasonal trend uncertainty estimates will also be developed.

Finally, we will examine the frequency, intensity, and duration of extreme events using the multi-sensor merged analysis for 1998 to the present for an accurate documentation of the modern era, and the gauge-only analysis for the depiction of long-term trends. The spatial distribution and temporal variations of precipitation extremes will be investigated in association with seasonal variations, short-term climate variability (ENSO, MJO, NAO), and long-term changes. Uncertainties will be considered in performing these examinations. We will also compare our results with precipitation fields from reanalyses, CMIP5 coupled simulations, and other climate models.

Xie, Pingping, Climate Prediction Center	**Improvement of a Multi-Instrument, Multi-Satellite Algorithm For High-Resolution Pole-to-Pole Global Precipitation Analyses**	**2010**

Abstract: Our proposal will aim at the goals of Research Categories 1.4 "Development of multi-instrument and multi-satellite algorithms within the general framework of statistical estimation" and 3.1 "Development and implementation of data assimilation precipitation analyses and downscaling of satellite precipitation information for hydrological modeling and prediction". Our proposed project comprises two components:

1. Improving the Kalman Filter – based CMORPH technique

We intend to work closely with NASA/GSFC multi-satellite algorithm developers and other PMM scientists to develop the next generation US unified GPM Level 3 merged precipitation algorithm. Specifically, we will

- Refine our Kalman Filter – based CMORPH to integrate estimates from PMW and IR observations into a high-resolution (8kmx30-min) quasi-global precipitation analysis From 60^{o}S-60^{o}N;

- Modify the Kalman Filter – based algorithm to produce precipitation analysis over a ***pole-to-pole*** global domain through integrating information from additional sources (e.g. numerical model simulations);

- Perform bias-correction for the all-satellite merged precipitation analysis through matching PDF of satellite estimates with that of a daily gauge analysis generated at NOAA/CPC; and

- Reprocess the high-resolution global precipitation analysis using the KF-based CMORPH with bias correction for the entire TRMM/GPM era.

2. Developing a new technique to generate CONUS precipitation analyses of finer resolution for

hydrological applications through combining information from the TRMM / GPM L3 global precipitation products and other sources. Specifically, we will

- Perform bias correction for radar data through PDF matching against a high-resolution (4kmx4km) CONUS hourly gauge analysis being developed at NOAA/CPC;
- Combine the bias-corrected satellite / radar estimates with the gauge analysis to define regional precipitation analysis at a fine resolution (4kmx4km/hourly);
- Further correction for orographic effects and wind undercatch may be conducted (through collaborations with other GPM scientists) by including additional information (topography, wind, surface temperature, moisture, ..); and
- Construct the regional precipitation analysis for the entire TRMM/GPM era.